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No difference in gait between posterior cruciate retention and the posterior stabilized design after total knee arthroplasty

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Abstract

Purpose In the present study, knee joint kinematics (e.g. knee flexion/extension) and kinetics (e.g. knee flexion moments) are assessed after total knee arthroplasty (TKA) between patients implanted with either a unilateral posterior stabilized (PS) and a posterior cruciate-retaining (PCR) design. It was hypothesized that maximum knee flexion during the loading response of the stance phase is greater in patients implanted with a PS design than in patients with a PCR design. Secondly, it was hypothesized that patients with a PS design show decreased knee flexion moments during loading, compared with patients implanted with a PCR design.

Methods This study examined two groups of TKA patients: one group ($n = 12$) with a PS design in which the posterior cruciate ligament (PCL) was sacrificed and the other ($n = 9$) with a PCR design. Gait analysis was used in level walking before and 6–9 months after surgery, to

assess knee joint kinematics and kinetics during the loading response of the stance phase.

Results No significant differences in maximum knee flexion between the two groups were found during the loading response of the stance phase. No significant differences in knee flexion moments were found either. Although in both groups knee flexion moments increased postoperatively, this was not statistically significant. In the contralateral (nonimplanted) knees, all mean knee flexion moments decreased postoperatively for both groups, yet this was not significant.

Conclusions The present gait analysis study showed no differences in kinematics and kinetics between the PS and the PCR TKP design. This might suggest that surgeons do not necessarily need to substitute the PCL by a PS design during TKA.

Level of evidence Prospective comparative study, Level II.

Keywords Knee · Arthroplasty · Gait · Posterior · Cruciate · Ligament

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Introduction

The debate as to whether to retain or sacrifice the posterior cruciate ligament (PCL) during total knee arthroplasty (TKA) surgery is an ongoing one. Advantages of PCL retention in posterior cruciate-retaining (PCR) total knee prosthesis (TKP) designs are preservation of the natural movements of the knee while maintaining stability from extension to flexion [14]. However, PCL retention leads to the need for adequate balancing of the ligament; inadequate balancing results in a deficient TKP with pain, instability and deteriorated range of motion (ROM) [16,

17]. When the decision is made to sacrifice the PCL, several adjustments in prosthetic design exist to compensate for its absence. The posterior stabilized (PS) design has a cam-post mechanism to facilitate anteroposterior stability and permits rollback of the femoral component on the tibial component during flexion.

There are studies using in vivo fluoroscopic analysis that suggest that PS designs show less abnormal knee kinematics (no paradoxical femoral rollback and greater quadriceps efficiency) and patients achieve greater knee flexion than with PCR designs [5–7, 21, 25]. From a Cochrane systematic review and a recent meta-analysis on this topic [13, 24], this greater flexion would be in concordance with an increased ROM seen in patients who use a PS design compared with a PCR design. However, little is known about whether this observed increase in flexion in the PS design after TKA is also expressed during walking, one of the most routine daily activities. The influence of prosthetic design on gait during level walking has been controversial [1], and to date, no gait analysis study has been conducted in patients implanted with the same type of prosthesis, differing only in presence (PS) or absence (PCR) of a cam-post mechanism.

In the present study, gait analysis was conducted to assess knee joint kinematics (e.g. knee flexion/extension) and kinetics (e.g. knee flexion moments) during the loading response of the stance phase, between patients implanted with either a unilateral PS or a PCR TKP. It was hypothesized that maximum knee flexion during the loading response of the stance phase is greater in patients implanted with a PS design than in patients with a PCR design. Secondly, it was hypothesized that patients with a PS design show decreased knee flexion moments compared with patients implanted with a PCR design.

Materials and methods

Twenty-four patients were included in this gait analysis study. Inclusion criteria were as follows: (1) being a patient at Martini Hospital (Groningen, The Netherlands) with primary symptomatic osteoarthritis of the knee; (2) a nonfixed varus or valgus deformity of $<10^\circ$; (3) age between 55 and 85 years; (4) body mass index (BMI) lower than 35 kg/m^2 ; (5) meeting criteria of class 1 or 2 of the American Society of Anesthesiologists (ASA); and (6) having given informed consent. Exclusion criteria were as follows: (1) inflammatory arthritis; (2) previous unicompartmental knee replacement; (3) tibial/femoral osteotomy; (4) cruciate ligament reconstruction; (5) flexion $<90^\circ$; (6) flexion contracture/extension deficit $>10^\circ$; (7) varus/valgus malalignment $>10^\circ$; or (8) any other lower extremity disease.

Included patients were part of a larger randomized controlled trial comparing the clinical results and

Fig. 1 Analysed peak values of knee joint kinematic (a) and kinetic (b) parameters: *FIHS* flexion at heel strike, *FILR* maximum flexion during loading response, *A* flexion range during loading response, *ExtTST* maximum extension at terminal stance, *F5* peak flexion in swing, *B* range of knee flexion/extension, *MLR* maximum flexion moment during loading response, *MTST* maximum extension moment during terminal stance

patient-reported outcome of two groups: one receiving the PS TKP design and one receiving the PCR TKP design [23]. From each group, 12 patients were randomly selected (by convenience sample) to undergo gait analysis both pre- and postoperatively. In both groups, the Anatomic Graduated Component (AGC, Biomet, Inc., Warsaw, IN, USA) TKP, either PCR or PS design, was used. Surgery was performed by two surgeons. The patella was resurfaced in three patients (1 PCR, 2 PS) with symptomatic patellofemoral osteoarthritis and/or anterior knee pain. All patients underwent an identical postoperative care and rehabilitation protocol.

Patient characteristics were scored at baseline. Passive motion of the knee (flexion, extension, ROM) and the Knee Society Score (KSS) were scored by an independent examiner, who was blinded to the type of procedure that had been performed [10]. Patients also completed the WOMAC questionnaire [2, 20].

Gait analysis

Gait analysis was conducted preoperatively and at 6–9 months postoperatively and took place at the motion laboratory of the Department of Rehabilitation Medicine, University Medical Center Groningen (UMCG). The laboratory is equipped with an 8-m-long walkway with two embedded force plates that measure ground reaction forces (AMTI, Watertown, MA, USA). Reflective markers were fixed with adhesive tape to anatomical bony landmarks as specified in the VICON Plug-in Gait lower body model [4, 12]. Anthropometric measurements were taken from each individual according to the VICON requirement and fed into the model. The reflective markers were tracked by an 8-camera VICON 370 motion capture system at a sampling rate of 100 Hz to measure knee joint ROM (Oxford Metrics, Oxford, UK). Accuracy and test–retest reliability have been checked for in previous research [9].

Patients walked barefoot at a self-selected, comfortable walking speed. To get accustomed to the test, the patients performed practice trials. For every patient, three trials with “clean” hits (a complete gait cycle) on both force plates were selected. Figure 1a shows the analysed peak values of the knee joint kinematics. Flexion at heel strike (FIHS), maximum flexion during loading response (FILR), flexion range during loading response (A) and maximum extension during terminal stance (ExtTST) were measured. Figure 1b

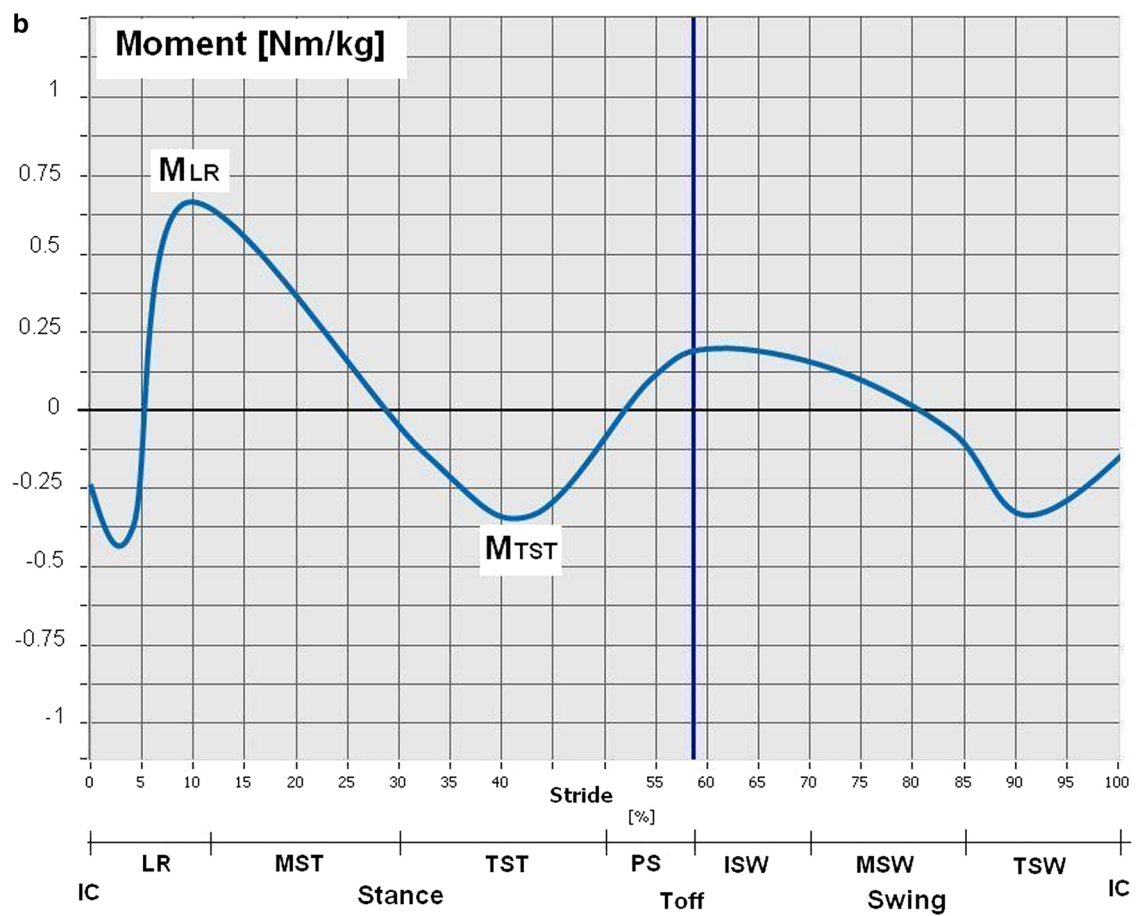
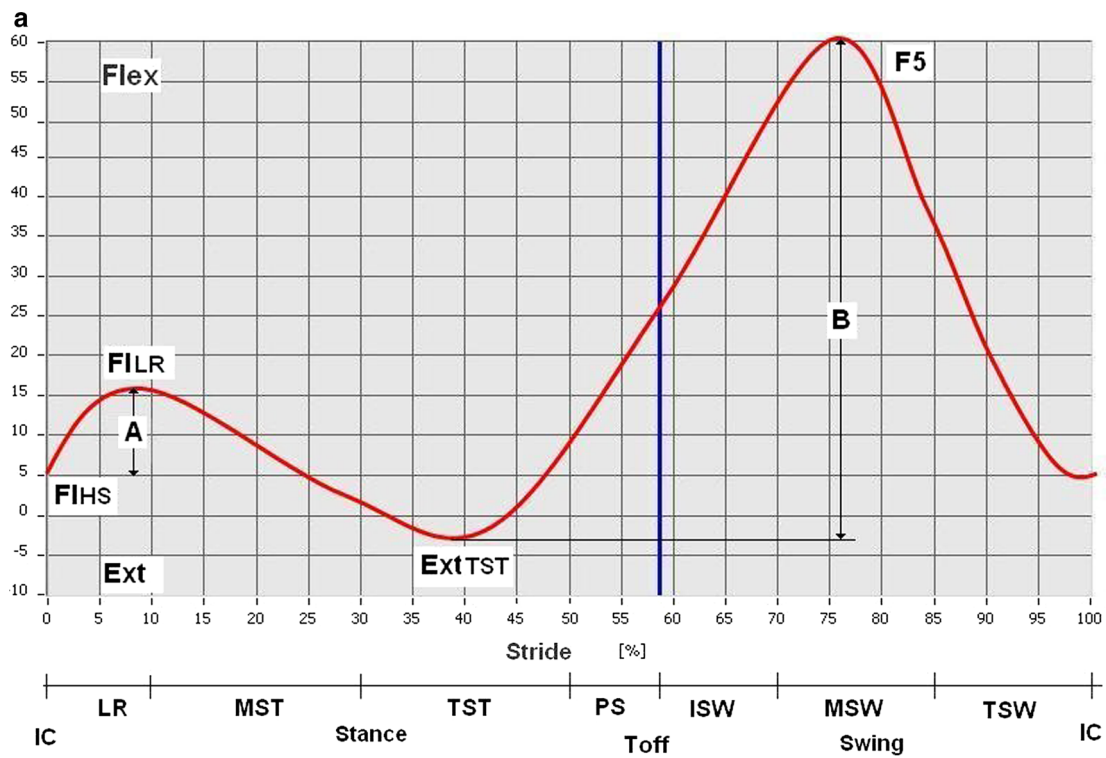


Table 1 Physical examination and questionnaire scores of the PCR ($n = 9$) and PS ($n = 12$) groups preoperatively and postoperatively, and difference between preoperative and postoperative values

	PCR group preop	PS group preop	<i>P</i> value	PCR group preop	PS group preop	<i>P</i> value	PCR group Δ preop–postop	PS group Δ preop–postop	<i>P</i> value
Passive knee extension (°)	−3 (5)	−3 (4)	n.s.	−5 (7)	−1 (3)	0.032	−2 (11)	2 (5)	n.s.
Passive knee flexion (°)	123 (15)	122 (14)	n.s.	118 (11)	121 (6)	n.s.	−4 (19)	0 (12)	n.s.
Range of motion (°)	119 (16)	119 (13)	n.s.	113 (11)	120 (7)	0.038	−6 (23)	2 (11)	n.s.
Knee Society Score	55 (13)	52 (8)	n.s.	77 (10)	83 (7)	n.s.	22 (14)	31 (10)	n.s.
WOMAC total score	53 (20)	46 (18)	n.s.	15 (10)	15 (12)	n.s.	−39 (19)	−31 (21)	n.s.

Displayed values are means (SD); Δ : difference; *p* values <0.05 in bold

shows the peak values of knee joint kinetics during the loading response of the stance phase. Maximum knee flexion moment during loading response (MLR) and maximum knee extension moment during terminal stance (MTST) were measured.

Kinematic and kinetic data were obtained for the implanted knees as well as the contralateral, nonimplanted knees. The latter was done to detect whether the loading of these knees changed after implantation of a TKP in the affected knee.

Ethics

The randomized controlled trial comparing the PCR and PS TKP designs, including the gait analysis part, was approved by the local Medical Ethical Committee “Stichting Beoordeling Ethiek Biomedisch Onderzoek” (BEBO), Assen, the Netherlands (registration number 2007-23) and is registered in the Netherlands Trial Registry (NTR1673).

Statistical analysis

A total number of 24 patients were included, in line with other gait analysis studies. Descriptive statistics were used for the characteristics of patients of the PS and PCR groups as well as for the physical examination (passive flexion, extension and ROM) and questionnaire scores (KSS, WOMAC) of both groups preoperatively and postoperatively.

The collected kinematic data of knee joint motion (°) were identified from each trial. This consisted of flexion at heel strike, maximum flexion during loading response, flexion range during loading response, and maximum extension at terminal stance. Kinetic data (knee flexion moments (Nm) during loading response and terminal stance in the sagittal plane) were calculated from the kinematic data and force platform measurements using standard inverse dynamics and anthropometric values from Winter [4, 12, 26]. All moments were normalized to body weight (Nm/kg). The means and standard deviations of preoperative and postoperative values as well as the difference between

preoperative and postoperative values of the kinematic and kinetic data were determined for the PCR and PS groups. The independent *t* test was used to compare the PCR and PS groups. These analyses were done for the implanted knee as well as for the contralateral, nonimplanted knee. A $p < 0.05$ was considered significant. Data were analysed using Microsoft Excel (Microsoft, Redmond, CA, USA).

Results

Of 24 patients included, two were unable to complete three trials with “clean” hits on the force plates during preoperative gait analysis and were therefore excluded. One patient developed a terminally malignant illness during follow-up and could not participate in the postoperative gait analysis. This left us with 21 patients (i.e. 21 knees, 12 PS group and 9 PCR group). The male/female ratio was 5/7 and 7/2 for the PS and the PCR group, respectively. Mean age was 75 (SD 6) years for the PS group and 72 (SD 8) years for the PCR group.

Physical examination and questionnaires

Table 1 shows the mean maximum passive knee flexion, extension, ROM, KSS and WOMAC questionnaire scores for the PCR and PS groups preoperatively and postoperatively, and the difference between preoperative and postoperative values. Preoperatively, no significant differences were seen between the two groups in any of the variables. Postoperatively, there was a significant difference in passive knee extension and ROM between the PCR and the PS group. Comparing the difference between preoperative and postoperative values between the two groups revealed no significant differences in any of the variables.

Knee kinematics and kinetics

Table 2 shows the mean knee angle parameters and knee moments during the loading response of the stance phase for the PS and PCR groups preoperatively and

Table 2 Knee angle parameters and knee moments during the loading response of the stance phase for the PCR ($n = 9$) and PS ($n = 12$) groups preoperatively and postoperatively, and difference between preoperative and postoperative values of the implanted knee

	PCR group preop	PS group preop	<i>P</i> value	PCR group preop	PS group preop	<i>P</i> value	PCR group Δ preop–postop	PS group Δ preop–postop	<i>P</i> value
Knee flexion angle (°)									
Flexion at heel strike	7.3 (5.6)	6.3 (5.2)	n.s.	9.6 (4.9)	8.7 (3.9)	n.s.	2.3 (6.5)	2.4 (6.6)	n.s.
Maximum flexion during loading response	13.7 (6.9)	11.4 (5.4)	n.s.	16.9 (5.4)	15.2 (5.0)	n.s.	3.2 (6.6)	3.8 (6.4)	n.s.
Flexion range during loading	6.4 (2.8)	5.1 (3.4)	n.s.	7.4 (2.8)	6.4 (2.7)	n.s.	1.0 (3.0)	1.3 (6.6)	n.s.
Maximum extension	5.6 (6.0)	5.7 (5.4)	n.s.	7.1 (4.2)	6.2 (4.4)	n.s.	1.5 (6.1)	0.5 (7.5)	n.s.
Knee moment (Nm/kg)									
Maximum flexion moment during loading response	0.12 (0.21)	0.13 (0.22)	n.s.	0.28 (0.20)	0.25 (0.24)	n.s.	0.16 (0.12)	0.12 (0.18)	n.s.
Maximum extension moment during terminal stance	−0.08 (0.14)	0.01 (0.15)	n.s.	0.01 (0.12)	0.02 (0.05)	n.s.	0.09 (0.19)	0.01 (0.17)	n.s.

Displayed values are means (SD); Δ : difference; *p* values <0.05 in bold

postoperatively, and the difference between preoperative and postoperative values for the implanted knee. Preoperatively as well as postoperatively, no significant differences were seen between the two groups in any of the variables.

In both groups, increased knee angles and knee moments were seen from the preoperative to postoperative periods; however, comparing the difference between preoperative and postoperative values between the PS and PCR groups revealed no statistically significant differences in any of the variables.

In the contralateral, nonimplanted knees, all knee angles (except for flexion range during loading) and all knee flexion moments decreased postoperatively in both groups. Comparing the difference between preoperative and postoperative values between the two groups showed no significant difference in any of the variables though (Table 3).

Discussion

The most important finding of the present study was that no significant differences in maximum knee flexion during the loading response of the stance phase were found between patients implanted with a PS TKP design and a PCR TKP design. Moreover, no significant differences in knee flexion moments (kinetics) were found.

Other gait analysis studies have compared PCR and PS designs using several types of prostheses from different manufacturers [3, 8], but an important difference with the present study is that all our patients were implanted with the same type of prosthesis (AGC, Biomet, Inc., Warsaw, IN, USA), differing only in presence (PS) or absence (PCR) of a cam-post mechanism. In this respect, the results

of the present study are in agreement with Bolanos et al., who performed gait analysis on PCR and PS designs and found no significant differences in ROM for the two prosthetic knees or in knee flexion moments during level walking. In a cohort of patients with bilateral PCR and PCL-sacrificing design, Dorr et al. did find greater knee flexion moments in the PCL-sacrificed knees, reporting that the PCL-sacrificing design was less efficient than the PCR design based on an increased knee flexion moment during level walking and suggesting that this could have potential effects on prosthetic longevity [8]. Their results are not in line with those of the present study; this could be due to the fact that PCL-sacrificing design in their study was not equipped with a cam-post mechanism; hence, it was not a “real” PS TKP design.

The lack of significant kinematic and kinetic differences between the two groups in our study suggests that, irrespective of the type of prosthetic design, patients express comparable gait cycle patterns during level walking. This raises the question of whether the presence or absence of a cam-post mechanism really is such a strong determinant of knee joint kinematics. This was also stated by Pandit et al. [18], who concluded that the similar kinematics exhibited by both PCR and PS configurations alludes to an ineffectiveness of the cam-post mechanism in controlling the position of the femur in flexion and suggested that surface geometry is a stronger determinant of knee kinematics than the presence or absence of a cam-post mechanism. This stresses the importance of studying two designs that differ only in one variable (presence or absence of a cam-post mechanism).

Patients with an arthritic, painful and stiff knee joint will compensate by loading the contralateral knee more. The

Table 3 Knee angle parameters and knee moments during the loading response of the stance phase for the PCR ($n = 9$) and PS ($n = 12$) groups preoperatively and postoperatively, and difference between preoperative and postoperative values of the contralateral, nonimplanted knee

	PCR group preop	PS group preop	<i>P</i> value	PCR group preop	PS group preop	<i>P</i> value	PCR group Δ preop-postop	PS group Δ preop-postop	<i>P</i> value
Knee flexion angle (°)									
Flexion at heel strike	9.9 (3.6)	9.3 (6.3)	n.s.	8.8 (4.3)	6.6 (4.6)	n.s.	−1.1 (3.7)	−2.7 (4.7)	n.s.
Maximum flexion during loading response	20.9 (4.8)	16.9 (8.1)	n.s.	19.9 (6.9)	14.9 (7.4)	0.004	−1.0 (4.5)	−2.0 (5.2)	n.s.
Flexion range during loading	10.9 (3.7)	7.6 (4.9)	0.002	11.1 (4.7)	8.3 (4.7)	n.s.	0.1 (3.4)	0.7 (2.8)	n.s.
Maximum extension	6.6 (5.5)	6.3 (7.1)	n.s.	4.5 (3.1)	4.8 (6.5)	n.s.	−2.1 (4.7)	−1.5 (5.3)	n.s.
Knee moment (Nm/kg)									
Maximum flexion moment during loading response	0.49 (0.16)	0.47 (0.25)	n.s.	0.44 (0.26)	0.39 (0.27)	n.s.	−0.05 (0.22)	−0.08 (0.22)	n.s.
Maximum extension moment during terminal stance	0.03 (0.29)	0.06 (0.24)	n.s.	−0.10 (0.19)	−0.07 (0.21)	n.s.	−0.10 (0.20)	−0.13 (0.21)	n.s.

Displayed values are means (SD); Δ : difference; *p* values <0.05 in bold

results of the present study seem to confirm this: although not statistically significant, there seems to be a decrease in knee flexion moments postoperatively in all contralateral, nonimplanted knees. By contrast, all implanted knees show increased knee flexion moments postoperatively—again, not statistically significant.

Limitations of the study are as follows: a small sample size, yet consistent with other gait analysis studies of patient groups after TKA [1, 3, 8, 11] and possibly that patients were evaluated only at the loading response and terminal stance phases during level walking, even though it is known that after TKP implantation patients show less knee flexion during the swing phase than unimpaired control individuals [15]. It is however specifically interesting to determine differences between the two different TKP designs during the loading response of the stance phase because, in that case, in the PCR design, the PCL should be functioning and potentially contributing to femoral rollback. Moreover, in the PS design, the substitution for the PCL is engaging during that phase. Therefore, the present study used maximum knee flexion during the loading response as primary outcome parameter. The reason gait analysis during level walking is conducted is that this is one of the most important, routine daily activities and the influence of prosthetic design on gait during level walking has been controversial [1].

In further research, it would be interesting to examine patients who are younger as well as more active and demanding. Mean age of the study population was 73 years, and mean age of the patient population in the literature is over 67 years [11, 19, 22]. These patients usually are low-demanding when it comes to physical activities of daily life. Subtle changes in knee stability after substituting or retaining the PCL in TKA surgery might be clinically

more relevant in these patients and may lead to different outcomes.

In the present study, no differences were found between the two different TKP designs in kinematics or kinetics during level walking. In terms of clinical relevance, this might suggest that surgeons who encounter a PCL-insufficient knee during TKA do not necessarily need to substitute the PCL using a PS design. However, due to the low number of patients, the present study only provides a first impression.

Conclusion

The present gait analysis study showed no differences in kinematics and kinetics between the PS and the PCR TKP design. This might suggest that surgeons do not necessarily need to substitute the PCL by a PS design during TKA.

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